Integrated Pneumatic Transporter-Incinerator-Afterburner Subsystem Development, Supported by NASA/Ames Research Center at General American Research Division, General American Transportation Company, from July 1973 through June 1974

Final Report

by

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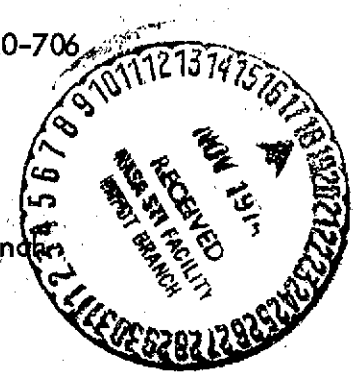

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Section I
Introduction

Since 1967, NASA Ames Research Center has via a series of three research and development contracts (NAS 2-4438, 2-5442 and 2-6386) supported work at General American Research Division, General American Transportation Company, Niles, Illinois, in the area of spacecraft waste management systems. The first of these contracts was aimed at evaluating microwave and incineration treatment methods for such systems, while the second was concerned with an experimental study of an incineration system including construction and testing of a prototype incinerator. Both these contracts were successfully completed, meeting contract objectives with minor (a few months) schedule slippages which were handled with no-cost extensions.

The third contract was originally let in April 1971 for design and fabrication of a prototype automatic transport system to move wastes to an incinerator on board a spacecraft, i.e., to operate in zero-gravity. This contract was subsequently twice modified: in April 1972 to change overall objective to that of an integrated, zero-gravity waste incineration system and to add phases of work concerned with a commode and debris collector, subsystems to treat noncondensible gases, supply oxygen to incinerator and afterburner, and remove and collect ash from the incinerator, and a zero-gravity condenser; in May 1973 to add phases of work including a tradeoff and interfacing study, in-depth performance testing of a totally integrated incineration system, and a study of autoclaving as a waste treatment method for spacecraft use.

Symptoms of difficulties in this work began to appear in late 1972, with an inadequate Phase B research report and the failure after July 1972 of the contractor to issue contractually-specified quarterly progress reports. As will be described in more detail below, I undertook in the summer of 1973 with NASA/Ames support a critical study of work done under this contract and its two predecessors which led

to a continuing involvement with the GARD work until its conclusion in June 1974. Much of the introductory material in the present document (including all of the next following section) was taken from my limited circulation report of July 1973 (1)*. This report was followed by a Revised Specification of Work from ARC to GARD, GARD Proposal 91887 in response and in October 1973 an official re-direction of effort under Contract No. NAS 2-6386.

1.1 Related NASA Contract Work

In addition to the three GARD (General American Research Division) contracts let by NASA/Ames Research Center (ARC), contracts for closely related work in spacecraft waste management system hardware development have been let by several other NASA groups. With joint AEC, USAF and NASA Headquarters funding, General Electric has been working for several years (since 1969) to develop a system which will accept feces, urine, condensate water, trash, etc., reprocess this input to obtain maximum amounts of potable water and incinerate the remainder to a storable dry ash. The G.E. system involves an auger-type transporter from the commode to a low pressure, moderate temperature evaporator. An air jet transporter brings material from a trash shredder to the evaporator, while liquids from the urine separator are pumped in. The resulting slurry undergoes evaporation with high temperature pyrolisis of the evolved vapor, then further processing and condensation to potable water. The solids from the evaporator are first squeezed in a solids pump, then carried to the incinerator in a cart system. This total system is fully designed and was undergoing verification testing at the end of 1973. Some significant difficulties have, not surprisingly in work of this type, been encountered and some re-design has resulted. G.E. has been reluctant to make full details of its work public, citing the necessity of protecting trade secrets, but on the whole it seems to be progressing well. Although originally funded through NASA Headquarters, this work is now being monitored by Marshall Space Flight Center, Huntsville.

Hamilton-Standard Division of United Aircraft (H-S) has been engaged in two lines of waste management work, both with Johnson Space Center (JSC) support.

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*Underscored numbers in parentheses indicate references listed at the end of this report.

The first was aimed at developing a complete waste management system based on space vacuum drying of waste and overboard dumping of off-gassing products. Residual solids accumulate in a tank which is exposed to space vacuum after each defecation. Air transport is used from the commode seat area to the storage tank. User testing on earth of a prototype system over an extended period produced generally favorable results. This system is probably very nearly ready for design of space-qualified hardware, i.e., its development cycle is virtually complete.

H-S has also done work in the area of steam and/or liquid reformation of waste. Following a decision at NASA Headquarters, funding for this work was moved from JSC to ARC and the work itself from H-S to the M.I.T. Chemical Engineering Department.

An alternate waste treatment method being developed by Lockheed Missile and Space Center with NASA Headquarters support is wet oxidation. Hardware built by LMSC for this system includes a grinder to reduce wastes to the proper consistency for treatment, a reactor vessel, heat exchanger, controls and pressure pumps.

1.2 Objectives, Tasks and Schedule of the Third GARD Contract Prior to Re-Direction

As originally negotiated in April of 1971, the third GARD contract (NAS 2-6386) called for three phases of work. Scheduled for completion in October 1971, Phase A was to consider several waste transporter concepts. A basic design was to be established and verification tested for each concept, each was to be analyzed for function, configuration, operating characteristics, reliability, maintainability, and human engineering, and for each it was to be established whether the concept was suitable for spacecraft application. Defined tasks to accomplish these objectives included design of a basic system for each of the three candidate concepts, fabrication of a simple model of each system, testing of each model, and modifications as required by design and performance criteria, evaluation and choice of a single most effective system for further development.

To be completed by May 1972, Phase B was to demonstrate suitability of the chosen system design and its conformance to design specifications, to demonstrate

that it was sanitary and suitable for zero-gravity, to determine flow capacity, size, weight and power requirements, and to determine suitability of system construction materials. Tasks called for included detailed prototype design, a formal NASA design review (per NASA publication SP-6502) prior to parts fabrication, fabrication and assembly, verification testing using human feces, urine distillate residue, paper and other miscellaneous waste materials, modifications to incorporate necessary changes indicated by verification testing and performance testing.

To be completed by October 1972, Phase C was to integrate the waste transporter with the four-man incineration unit which GARD had developed under Contract No. NASA 2-5442. The incinerator was to be modified if necessary to accommodate the transport system components. Design modifications were to be carried out on paper so that the GARD transporter could be used with the isotope-heated incineration unit under joint development by AEC, NASA and the USAF, i.e., the G.E. incinerator. Tasks included modification of the incinerator design, fabrication and testing, and the on-paper design changes for use of the GARD transporter with the G.E. incinerator.

In April 1972, an increase in scope and a 15-month time extension of the then current GARD contract (NAS 2-6386) was negotiated. The basic objective of the work was changed from transporter development and integration with an existing incinerator to development of an integrated, zero-gravity waste management system. To accomplish this broadened objective, Phases D, E and F were added to the work. To be completed by April 1973, Phase D was to provide the means for users to input material to the transporter, specifically a commode and separate trash chopper for food scraps and housekeeping debris. To be completed by July 1973, Phase E was to be concerned with an oxidant supply subsystem to satisfy the needs of both incinerator and afterburner, a product gas collection subsystem (if the rumored no-overboard-dumping policy became a reality, this would be necessary) and an ash removal and collection subsystem for the incinerator. To be completed by January 1974, Phase F was to provide a zero-gravity condenser to process the output of the incinerator

afterburner. Phases D, E and F each called for the following seven tasks: design and analysis, manufacture, design verification testing, integration, performance testing, shipment and documentation.

In May 1973, another increase in scope to NAS 2-6386 was negotiated and a Phase G was added to the contract. Phase G was to include a tradeoff and interfacing study (trading off the GARD system with other candidate systems; interfacing the GARD system with a spacecraft), in-depth performance testing of a totally integrated zero-gravity dry incineration system and a study of autoclaving as a waste management technique.

1.3 Performance of GARD Prior to Re-Direction

GARD issued a Phase A research report in December 1971, indicating the work was substantially on schedule at this point (Phase A was to be completed in October 1971). In my view the report indicated successful completion of this phase of the work and the report itself was an adequate account thereof.

Though Phase B was scheduled for completion in May 1972, no Phase B research report appeared until October 1972. This report included detailed results of induced air flow tests for various sections of the pneumatic transporter separately and for the system as a whole. It included vague descriptions only of the results of dropping solids and liquids into the center of the input section of the transporter (some material was blown back out), placing liquid drops on a pressurized porous plate (no air cushion was observed) and suspending water droplets in a porous tube (results were apparently uniformly poor). I concluded from my reading of the report that all tests described which were directly related to system performance as a transporter indicated non-feasibility (though it is not my opinion based on everything I have learned that pneumatic transport of human waste is infeasible). Yet the stated conclusion of GARD (page 4-1 of the Phase B research report) is that "on the basis of tests conducted during Phase B... the basic concepts of creating a pneumatic drag effect with pressurized nozzles and supporting wastes on an air cushion have been shown feasible." It is my opinion that the Phase B report conclusions were not warranted and should have been rejected as unsatisfactory relative to contractural requirements by the NASA technical

monitor at the preliminary review stage; this would have precipitated earlier (prior to June, 1973) discussions of what should be done about the substantial schedule slippages which had by then occurred in the contract.

Although explicitly specified in the contract, no quarterly progress reports were issued between July 1972 and the summer of 1973. No written reports of any kind, in fact, were issued since the October 1972 Phase B research report. Following re-direction, the missing quarterly reports were finally issued and a quite comprehensive interim summary report of all NAS 2-6386 work to date (2) was released in October 1973.

1.4 Role of the Author of This Report

I originally became involved with the GARD effort under contract no. NAS 2-6386 when a mini-grant to Stanford University from NASA Ames Research Center under the auspices of the NASA University Consortium enabled me to undertake a critical study of the work during the summer of 1973. This study included examination of voluminous file material at Ames Research Center, extended conversations with the then Technical Monitor Dr. Jacob Shapira and a site visit at GARD facilities in Niles, Illinois, in late June 1973. I then wrote the limited circulation report (1) mentioned above. In ensuing discussions with Environmental Control Research Branch Chief Dr. Philip Quattrone and Dr. Shapira, I recommended that the GARD effort under the then-current work specification be terminated and that a revised specification of narrower focus be issued. At their request I drafted a revised work specification (details of which are discussed briefly in Section 2.1 of this report) which was subsequently formally transmitted by ARC to GARD.

GARD responded with Proposal 91887 for development of an integrated, zero-g pneumatic transporter/dry incinerator/catalytic afterburner subsystem for spacecraft human wastes. I reviewed the proposal and recommended on 28 September 1973 that it be accepted. GARD was officially notified of acceptance of this proposal in mid-October and commenced the re-directed effort immediately.

Since I was willing to continue being involved as a part-time participant in the work and Dr. Quattrone and Dr. Shapira were eager to have me do so, I proposed

to NASA the funding of a modest continuing effort; as a result, I was awarded NASA/Ames Grant No. NGR 05-020-706. My level of effort under this grant consisted of one (usually lengthy) phone conference each week with GARD personnel working on the project, a half-dozen site visits, critical review of reports, specifications and drawings,* and occasional reports by phone or in person to Dr. Quattrone. Dr. Shapira was becoming increasingly incapacitated by illness by fall 1973, so that even prior to his death in November, 1973, I had become a sort of unofficial surrogate Technical Monitor for the GARD effort and continued in that capacity until the end of the contract 30 June 1974.

1.5 Purposes of This Report

The present report is the official final report of my effort under NASA/Ames Grant No. NGR 05-020-706. Its major objective is to review critically the GARD effort since re-direction at the end of summer 1973 and hence together with my previous report (1) it is intended to serve as an assessment of the entire GARD effort under Contract No. NAS 2-6386. My own function during my involvement with the work will also be reviewed briefly. The report closes traditionally with conclusions and recommendations, many of the latter carried over with slight changes from (1).

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*In fairness to GARD, I should acknowledge that some of the criticism in this report was made with the benefit of hindsight. Other criticism was not strongly emphasized in my contact with GARD personnel during the course of the work because of my opinion that insufficient resources were available at GARD to respond to it effectively; in these instances I felt that I would, on balance, only hinder the progress of the work by speaking out. See also Section 3.2.

Section 2
Review of GARD Effort Since Re-Direction

2.1 Objectives of Revised Specification of Work and of GARD Proposal 91887; Comments on Schedule and Budget

The revised work specification transmitted to GARD by NASA in August 1973 indicated that further effort under Contract No. NAS 2-6386 was to have two major objectives:

1. To develop and characterize the technologies of pneumatic transport and of incineration with catalytic afterburning as used in human waste management systems for spacecraft so that a reliable basis is provided for flight system tradeoff studies, flight hardware design, etc., including especially the effects of zero-gravity operation.
2. To design a prototype integrated pneumatic transporter-incinerator-afterburner subsystem and to perform comprehensive testing of the prototype with real waste materials.

Four tasks were described in detail in the specification. Task titles included:

1. Particle Size Reduction Mechanism for Feces
2. Technology Development and Prototype Hardware Design and Testing: Subsystem Components (the three major components were identified as the transporter, incinerator and afterburner with particle size reduction mechanism included as part of either transporter or incinerator pending the results of Task 1)
3. Technology Development and Prototype Hardware Design and Testing: Integrated Subsystem
4. Analysis

Results of previous experimental work by GARD indicated that particle size reduction (i.e., breaking up the bolus into smaller fragments) was a requirement for proper incineration; GARD's inability to find a suitable mechanism for accomplishing this had been perhaps the principle barrier to progress prior to re-direction. Given a solution to the particle size reduction problem, pneumatic transport of waste materials from

the collection site to the incinerator and the incinerator itself were the most important undeveloped components of a complete waste management system for spacecraft based on the dry incineration concept. The afterburner was mentioned as one of the components to be worked on in Task 2 only because it was a necessary part of an integrated waste processing subsystem; it was anticipated, however, that the catalytic afterburner developed by GARD during its work on the previous contract would be used virtually unchanged (except perhaps for scaling up) in the integrated subsystem specified in Task 3. This third task was to be concerned principally with extensive testing of the integrated subsystem made up of components developed and tested in Task 2.

Analysis was called out separately as Task 4 not because it was intended that analytical effort be separate from the development and design work of the other tasks, but because previous GARD effort had seemed so poorly informed by even order-of-magnitude analytical techniques that I felt the subject should be given special emphasis.

GARD Proposal 91887 was prepared in response to the revised work specification. In it GARD consolidated Tasks 1 through 4 of the specification into Tasks I and II. Added were Task III for a paper study of autoclaving as a possible waste management technique for spacecraft (my interaction with performance of this task was essentially nil and it will not be discussed in this report) and Task IV for documentation. In Section 1.2 of the proposal, GARD proposed "a modified program to:

(1) Develop and characterize the technologies of pneumatic transport and of dry incineration with catalytic afterburning of product gases to provide a reliable basis for flight system trade-off studies, flight hardware design, etc., including the effects of zero-gravity operations.

(2) Design a prototype integrated pneumatic transporter/dry incinerator/ catalytic afterburner subsystem and to perform comprehensive testing of this subsystem with actual waste materials."

A third objective to be satisfied by the autoclaving study was also stated.

On page 2-13 of the proposal, Dr. Stephen Fields was proposed as an addition to the GARD project team whose "past experience in the area of fluid mechanics and gas dynamics should be of particular value in analyzing and optimizing the pneumatic transport mechanism."

It was explicitly recognized in my conversations with GARD personnel and with Dr. Quattrone before and after this proposal was submitted to NASA that both the time and money available (i.e., the time remaining before scheduled completion of Contract No. NAS 2-6386 and unexpended funds in the then-current contract budget) were insufficient for accomplishment of the objectives stated in the proposal. Although it was clear that no further funding would be available, a no-cost time extension was expected to be necessary (as it proved to be). The objective of the re-directed effort was to move as far as possible toward achievement of the stated goals within the constraints of available funds. It was apparent that a good many of the dollars expended prior to re-direction had not accomplished the NASA objectives and it seemed equally obvious that recovery of that loss was very unlikely. Therefore, the acceptable alternative for NASA was to try to get as much technical information as possible for the remaining funds.

2.2 Brief Chronology of Events

The revised specification of work was transmitted to GARD in early August 1973. It instructed GARD to terminate all tasks associated with Phases A through G of the then-current specification and to initiate the tasks of the new specification. There was to be no change in contract price and the scope of each task in the new specification was to be subject to negotiation upon receipt of the new GARD proposal.

The following account of subsequent events is based primarily on my telephone calls and personal visits to GARD and possibly errs in some details. GARD apparently ceased all work on the contract upon receipt or prior to receipt of the revised specification except for preparation of the missing quarterly reports, the Interim Summary Report (which was to describe results of all work on NAS 2-6386 prior to re-direction) and the new proposal. In mid-September, the new proposal reached NASA. By the end of September I had reviewed it and recommended acceptance. And in mid-October 1973, GARD received official notification that it should commence work as described in its Proposal 91887.

Consideration of alternative concepts for the particle reduction mechanism, pneumatic transporter configuration, and incinerator design continued through 1973

and into early 1974. The various exploratory tests which were performed and the concepts considered are well described in the Component Performance Summary Report (3) of April 1974. In early spring 1974, detail design of the components to be used in the integrated subsystem testing began. Materials procurement and component fabrication took until May 1974; preliminary testing and system debugging until late in May. The final series of tests was concluded in mid-June and the final report then written in the two weeks before expiration of the no-cost extended contract on 30 June 1974.

2.3 Accomplishments

Perhaps the most important positive accomplishment of GARD effort on Contract No. NAS 2-6386 was the design and limited test results of the six-inch diameter (6 man design capacity) rotating paddle incinerator (4). Although there has been no really hard evidence either experimental or analytical that this is so, it seems reasonable to assume that the rotating paddle incinerator is much closer to a configuration which would operate successfully in zero-g than the stationary incinerator tested on the previous GARD contract.

During this work GARD performed an extensive compilation and evaluation of alternatives for particle reduction mechanism, pneumatic transporter and incinerator configurations -- all of which would, of course, be required in a complete functional system. These together with operational specifications for each component are reported quite completely in (3) and should be useful in any future development and design effort in this area.

A number of particle reduction mechanism concepts underwent exploratory evaluation; results here were mostly negative. However, the reported results are of value since the nonfeasible concepts need not be tried again. Even the shear bar concept which was incorporated in the final incinerator design proved not fully satisfactory in testing as reported in (4).

Some insight into solid and fluid particle motion within a rotating paddle incinerator is offered by the reported results of testing a transparent plastic incinerator model (3) and certainly the account of the successive trials of the 4-inch diameter incinerator (3) should be read by anyone continuing work in this area.

2.4 Uncompleted Work

Any account of work that did not get accomplished on NAS 2-6386 should be prefaced with a repetition of my earlier acknowledgement that everyone involved knew that full accomplishment of the objectives formulated at the time of re-direction was extremely unlikely given the time and money remaining. It is nonetheless disappointing to me in retrospect that several important categories of work remained nearly or totally untouched. These include:

1. Pneumatic transporter development past the "on-paper" concept evaluation
2. Comprehensive testing sufficient to support technology characterization
3. Substantial analytical work of any kind
4. Zero-g vs. one-g issues

I remarked in my earlier report (1) that there was a tendency for both GARD and NASA personnel involved with this contract to focus on hardware development, to the detriment of more fundamental work aimed at understanding and characterizing in detail sufficient for design of the technology areas involved. Despite my efforts in the revised specification and GARD's apparent good intentions in Proposal 91887, old habits and time pressure combined to maintain the old focus virtually intact.

Two men who had long been involved in GARD work in this area left the organization during the post-re-direction effort. If more time had been available, this probably could have had a net positive effect. As it was, however, it simply increased the administrative burden on the new Project Engineer, Dr. Fields. My personal impression of Dr. Fields was of a man of very substantial theoretical/analytical/experimental talent who never had a real chance to apply his significant engineering scientific skills to the problems of this project because his time was consumed with managing it.

2.5 Comments on Component and Integrated Subsystem Performance Summary Reports, NASA CR 114763 and 114764

One thing which had particularly disturbed me when reading GARD technical reports on NAS 2-6386 which had been issued prior to contract re-direction, was

the frequent failure to report negative results completely. The three major reports prepared thereafter (the Interim Summary Report (2) and the two which are the subject of this section) seemed to me by refreshing contrast very complete and frank, particularly in the narrative descriptions of actual results which made up the body of these documents. Some mild advocacy seems to me to be residual in the introductory material in these reports, however.

Two of the conclusions reported at the end of the integrated subsystem report (4) would be directly useful in future tradeoff studies of waste management system concepts, i.e., energy consumption of the subsystem estimated to be 2 kwhr per man per day and oxygen consumption approximately one gram per gram of waste solids. Both performance reports, however, would probably be much more useful to future workers if a conscientious effort had been made to abstract and highlight all information contained in or inferrable from the test results which would be useful in system concept tradeoff studies. Dr. Fields did treat many of these questions conscientiously in his lengthy letter (5) of 14 August 1974 to Mr. David Putnam of the SAE Study Group IV (see Sections 4.1 and 4.3) which perhaps should be made generally available as a supplement to (4).

I had explicitly included a requirement in the revised work specification for written operational specifications for both components and integrated subsystem because of my impression that GARD personnel had been having difficulty separating functional requirements from specific concepts for accomplishing them; with the particle reduction mechanism problem, for example, they seemed to be suffering from a classic case of locking onto a concept early in the development cycle and not not being able to let go of it even though results of feasibility trials had been very discouraging. The operational specifications included in Section 2 of the component report (3) seem to me to have met at least my intended purpose for them well, i.e., that they be capable of serving as criteria for judging candidate alternative concepts but not embody unnecessary preconceptions as to operating principle, configuration, etc. Some parts of the subsystem operational specification presented as Appendix A of the subsystem report also serve this purpose well; others, however, represent merely a description of the designed prototype. It would make better sense to me to separate

the descriptive material specific to this design from the specification of how any such subsystem ought to operate.

Two unexplained inconsistencies in the test results described in the subsystem report are adequately acknowledged: the substantial mass balance deficits and the doubled O_2 consumption when these results are compared with those of the previous contract tests of the stationary incinerator. The mass balance deficits were subsequently explained in Dr. Fields' letter (5).

In closing this section, I want to emphasize my overall impression that these are good reports of the work actually accomplished since re-direction. The stated objective of the revised work specification regarding reports and reporting was in my opinion amply satisfied.

Section 3
Review of the Author's Role in Effort since Re-Direction

3.1 Prior to Mid-October 1973

My work up to the time of GARD's commencing work under the terms of Proposal 91887 in mid-October 1973 was apparently quite effective. I brought a fresh viewpoint to a badly stagnated effort and because of my lack of permanent allegiance to either NASA or GARD could afford politically to grasp the nettle of acknowledging that something had decidedly gone wrong. The majority of my July 1973 report still appears to be applicable to the GARD work from the perspective of a year later.

I am also still satisfied with the revised work specification, though I have been forced to acknowledge that it was totally unrealistic in scope in the context of time and dollars available and the capability available at GARD. The revised specification would have been better couched in more specific, less ambitious detail. I do not, however, in any way disavow the viewpoint expressed therein concerning appropriate fundamental objectives for research and development work of this type. Specifically, I remain convinced that technology development and characterization should be higher objectives than specific hardware design and test in work this far upstream of flight hardware. I also recognize fully the difficulties of remaining true to this ideal when upper-level NASA management wants tangible evidence of something functional for R & D dollars expended.

3.2 Subsequent to Mid-October 1973

It does not really seem possible for me to effectively assess my contribution or lack thereof once the re-directed effort had begun, though perhaps the following observations may help anyone else who tries to do so. Whether GARD perceived me as a pest, a help or something in between I do not know. Such a perception would be only a partial truth anyway, relative to accomplishment of NASA objectives.

I probably made some direct technical contribution in the sense of solving or suggesting directions toward solving engineering problems. But probably my major

contribution consisted in being someone who cared whether things were moving or not; I served as a sounding board and psychological support for a GARD project team which had been apparently badly disspirited prior to re-direction.

My relationship with GARD personnel at the working engineer level was always very friendly and cooperative. My sense was that they were fully as concerned as I that the best effort possible be made with the time and funds remaining to be expended. I never had any indication that the irregularity of my formal status (i.e., that I was not a NASA employee and an official Technical Monitor) interfered with their willingness to let me know what was happening and to listen to my opinions.

Section 4
Conclusions and Recommendations

4.1 Re: The GARD Effort

My final evaluation is that the GARD effort since re-direction was reasonable and workmanlike but certainly not overwhelmingly impressive in view of the time and funding available. With prospects for future funding poor, there was little motivation for higher company management to insist upon and support a superlative effort. Substantial progress was made during the re-directed effort nonetheless and the results of the work stand a fair chance of being genuinely useful in the longer-term perspective of spacecraft human waste management system development.

I hesitate to draw conclusions or to make recommendations regarding the suitability of GARD vs. other possible contractors for future work in this area. Although I did serve for a time as a member of Study Group IV under NASA Contract NASW-2439 which was concerned with such comparative evaluations (see Section 4.3), my total effort in the area of spacecraft human waste management systems was so dominated by the time I spent on the GARD work that I feel unqualified to make such comparisons.

The overall results of all GARD effort on Contract No. NAS 2-6386 must, of course, be termed quite disappointing though that is primarily due to poor performance prior to re-direction. Certainly a careful evaluation of GARD capability relative to any specific future effort would be in order prior to letting a contract, as well as close-in, technically qualified monitoring by NASA personnel.

4.2 Questions Concerning NASA Conduct of R & D Efforts in this Area

In my July 1973 report (1), I included a list of issues raised by my investigation to date. The list was presented in the form of a series of ten questions proceeding approximately in order from the most sweeping, requiring policy decisions at the highest level, to the most specific; partial or full answers and their sources were included for each question to which I had been offered an answer or had thought of

one myself. The last question had to do with technical specifics of the GARD effort and has already been resolved for better or for worse by the conclusion of this work. The other questions seem to me to be fully as important today as in July, 1973, and I therefore repeat them below. I have revised the answers somewhat in light of intervening events.

1. Why does NASA invest in development of sophisticated waste management systems when future manned missions have been so severely curtailed?

   Dr. Shapira of NASA-ARC cited strong crew complaints about manual "baggie" systems used in the past. Longer duration missions seem certain to fly sooner or later.

2. Why is an absolute ban on overboard dumping even rumored?

   Even relatively innocuous gaseous products may foul sensitive astronomical measurement equipment, particularly lens surfaces. There is also concern about the long-term effects of introducing contaminated micro-organisms into outer space. The products dumped by thrust jets used for station-keeping are always mentioned in discussions of this issue; their effect on instruments is not known apparently. The overboard dumping ban is to my knowledge still in the nebulous status of "may be imposed" and gives the contractor for waste management system development the impression that NASA does not know what it wants. The overboard dumping ban was included as a contingency in the GARD contract prior to re-direction (the product gas collection system called for in pre-re-direction Phase E-2 would be unnecessary if dumping is permitted).

3. Why had an automated baggie or canister system with autoclaving not been seriously considered?

   GARD stated that a proposal had been submitted "years ago", but NASA was uninterested. No clear NASA position on this issue had been obvious to me, though Task III of the re-directed contract produced a paper-only study of autoclaving; no doubt other consideration of the technique has been given somewhere in the maze of various NASA efforts on waste management.

4. Why did NASA fund parallel path development efforts with different contractors when missions are so far off and uncertain?

NASA replied that missions are not so very far off when realistic delays between development and qualified space hardware are considered. Perhaps more importantly, government competitive bidding requirements seem to necessitate maintaining more than one contractor capable of doing such work.

5. Why did NASA supervise four different contractors doing closely related work from four different activity centers, practically guaranteeing total lack of coordination?

This writer suspects that competition between various NASA units, each seeking the glory of having developed the system which actually flies, is at least as important as the need to protect trade secrets of the various contractors.

6. Why is NASA technical and fiscal monitoring of contract work so completely separated, when the result is frequently inferior technical reports submitted to satisfy a schedule rigidly enforced by the fiscal monitor?

This is no doubt the result of attempts to provide checks and balances within the government, avoiding the concentration of too much power in the hands of one man, on the one hand, and to avoid loading the technical monitor with unnecessary adminstrative detail, on the other. It is perhaps also the result of a similar separation at the highest level; i.e., a relatively technically unsophisticated Congress seeking tangible evidence of value received for dollars spent pushes for hardware delivered on schedule, while NASA management recognizes that it is often more important to invest first in fully understanding a basic technology. In any case, GARD had certainly felt strong pressures to produce a hardware system which "works" (however poorly), rather than focus on technology exploration in its development work under this contract.

7. Why was a contract written for a complete system (i.e., the expansion in scope of NAS 2-6386 prior to re-direction to include Phases D, E and F) when the central concept of coupled pneumatic transport and incineration had not yet been proven feasible?

Apparently NASA-ARC felt this was necessary because the alternative systems being backed by other NASA centers were nearing readiness for complete system testing.

8. Why was a contract with a firm, tight schedule written when it was unknown a priori whether one, none, or many ways were possible to solve various technical problems associated with the work?

Last summer I answered this one with the observation that GARD had indicated in its proposal a high level of confidence in concepts which had been validated by neither analysis or experiment, while NASA was (in my opinion) trying to use a tight schedule as a substitute for effective in-close technical supervision. After my own efforts at writing (what seemed to me) a more sensible work specification and at providing in-close technical supervision, I am left with the sense that in exploratory R & D work such as this, NASA is very much at the mercy of the contractor once a contract has been signed. The technical monitor can never make up for deficiencies in the contractor and short of threatening to cut off funding has little power other than that of persuasion to influence what the contractor actually does day by day. A specific schedule is, in my opinion, a good thing if it is realistic and truly agreed to in spirit by the contractor. A schedule everyone knows cannot be met is worse than none. The fundamental problem of how to schedule work when no one can know before doing it how long it will really take is endemic to research and advanced development work and knows of no real solution that I have ever seen.

9. Why was there not effective technical monitoring prior to re-direction when amounts of money this large were involved?

Engineering personnel were simply not available within the cognizant NASA group, though this contract was largely concerned with the development of engineered hardware. The scientifically trained monitor assigned to this contract was overburdened with other work and had personal problems which reduced his effectiveness. Travel budget monies permitted less than two site visits by the technical monitor per year. The solution employed after re-direction,

i.e., a NASA grant to permit the participation of someone in a position like mine, might be used again. I would not personally be interested; though I know I learned enormously from this experience, work in this area has not become a mainstream interest for me. For an academic person already seriously involved or seeking means of entry to a field in which he intends to do serious work of his own, a stint as a surrogate technical monitor might well be attractive and beneficial.

4.3 Recommendations for Action by NASA

My earlier report concluded with four recommendations for action, the last two of which dealt specifically with the GARD effort which has now been concluded. The first two were directed to NASA more generally and had to do, respectively, with a NASA-wide review of work on human waste management systems for spacecraft and with the process of technical monitoring of work in this area.

The idea of a critical review committee was not mine and was already being implemented in the summer of 1973 under the leadership of Dr. Jack Spurlock of Theodore Jonas/Associates, Arlington, VA, and with the support of NASA Contract NASW-2439 let to the Society of Automotive Engineers. I participated in the deliberations of this study group during the last four months of 1973. In December 1973 the study group met with NASA Headquarters personnel in Washington and an interim report was prepared early in 1974. To the best of my knowledge, this report was never circulated beyond NASA Headquarters and the members of the study group.

As of the end of 1973, the study group had identified the need for more technical detail and some specific additional experimental results not then available concerning the systems under development at General Electric and GARD. The group had agreed that until this information was available, further progress with its tasks was not feasible. Of even greater importance, however, was the apparent uncertainty within NASA as to whether further effort in the area of spacecraft human waste management systems was to be supported at all and if so what the objectives

of such work ought to be. The study group therefore did no further work until very recently (July 1974) when it apparently began again with its NASA-wide review effort. Since I am no longer a member of the group, my information about its current activities is limited; questions should be directed to Dr. Spurlock.

My recommendations in July 1973 for the charge to such a review group still seem valid to me and I therefore now repeat them virtually unchanged.

Recommendations: a small committee of critical, active scientists and engineers from outside the NASA establishment should be provided the financial means to review objectively all NASA work on human waste management systems for spacecraft. This group should undertake at least the following tasks:

1. Establish realistic general specifications for second and third generation systems with estimated intermediate milestone dates and target dates for operational deployment (Skylab system is defined as the first generation system).
2. Review all system concepts currently under consideration or which have been suggested. Decide whether or not a detailed, formal tradeoff study is required before recommending a concept for the second generation system. Help NASA perform or contract for this tradeoff study if it is necessary.
3. Prepare written recommendations for the NASA statement of work for the second generation system development contractor(s); decide whether further technology development work is required before contracting for development of a specific system.
4. Review the multi-contractor policy. If it must be maintained inflexibly, consider alternatives to the present duplication of effort; e.g., give an incinerator contract to G.E., a transporter contract to GARD and a commode contract to Hamilton-Standard and force them to work together by effective, centralized technical monitoring.
5. Review the notion of an overboard dumping ban and recommend a NASA policy on this issue for development efforts on human waste management systems.
6. Recommend a procedure and date whereby this group will reconstitute itself to go through a similar exercise for the third generation system.

With regard also to the process of technical monitoring of work in this area, my recommendations for action made a year ago seem valid still with minor modifications and additions.

Recommendation: provide effective technical monitoring of NASA contract work on human waste management systems for spacecraft by implementing at least the following specific actions:

1. Centralize all human waste management system development contract monitoring and administration at one NASA location under technical supervision of a two-man scientist/engineer team, thus eliminating wasteful competition between centers, promotion of "pet" systems and contractors, etc.
2. Scale the workload on the technical monitoring team so effective, in-close technical collaboration with the monitored effort is possible. Consider supplementing the team with part-time surrogate monitors from outside NASA using my participation in the GARD effort as a starting point for designing the best format(s).
3. Provide travel funds for at least four site visits to each contractor per year.
4. Make it an explicit NASA policy to be implemented by the technical monitor team that maximum interchange of information occur at all times among all contractors working in the human waste management area.

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